SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AD-A211 650	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 89-1151
6a. NAME OF PERFORMING ORGANIZATION LAWRENCE E. AREND EYE RESEARCH INSTITUTE / 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
6c. ADDRESS (City, State, and ZIP Code) BOSTON, MA 02114	7b. ADDRESS (City, State, and ZIP Code) BUILDING 410 BOLLING AFB DC 20332
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR / 8b. OFFICE SYMBOL (If applicable) NL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-86-0128
8c. ADDRESS (City, State, and ZIP Code) Bldg. 410 Bolling AFB, DC 20332-6448	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 61102F / PROJECT NO. 2313 / TASK NO. A-5 / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification) Eye Movements + Spatial Pattern Vision

12. PERSONAL AUTHOR(S) AREND, LAWRENCE E.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 3/1/86 TO 4/30/89	89 JULY 15	12

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	SPATIAL PATTERN VISION, VISUAL ILLUSIONS, ~~COLOR CONSTANCY,~~ COLOR VISION. (AW)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Models of lightness and color perception must take account of human color constancy, a tendency for apparent surface color to be relatively independent of the color and intensity of the illuminating light source.

Observers matched the lightnesses and brightnesses of regions in simple and complex achromatic spatial patterns. The data showed that the observers' knowledge of the surface reflectances (revealed by lightness matches) was unaffected by changing brightness of the same surfaces (revealed by brightness matches).

In the analogous chromatic experiments, observers matched the hue and saturation of patches or the patches' apparent surface colors. The observers' knowledge of the surface colors was not as reliable as in the achromatic case. Patches' hues and saturations matched when their chromaticities were approximately the same. Shifts of hue attributable to simultaneous color contrast were in the correct direction but too small to produce hue constancy. Keywords: Visual Perception.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclass
22a. NAME OF RESPONSIBLE INDIVIDUAL John F. Tangney	22b. TELEPHONE (Include Area Code) (202) 767-5021 / 22c. OFFICE SYMBOL NL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

DTIC ELECTE AUG 21 1989

89 8 21 060

30 AUG 1989

VI. INVENTIONS

There were no patentable inventions under this project.

AFOSR-TR- 89-1151

FINAL TECHNICAL REPORT
3/1/86-4/30/89

GRANT AFOSR 86-0128

Lawrence E. Arend
Principal Investigator

I. OBJECTIVES

A. Lightness and Color Constancy

We proposed to extend our first experiments on simultaneous lightness and color constancy in complex spatial patterns to consider several additional variables. In achromatic work this included extension to test patches spanning the gray scale and investigation of smoothly changing illumination distributions. In chromatic work the proposed new manipulations included relaxing the restriction of test-pattern color patches to equal Munsell value. We also proposed to examine the role of exposure duration (important as a test of our procedures for control of temporal color adaptation). It was clear from interactions with researchers at Stanford and elsewhere in the first program period that understanding of simultaneous mechanisms will require careful study of the relationship between temporal adaptation constancy mechanisms and simultaneous mechanisms.

B. Model Development

Our basic thresholded-gradient-integration model provided crude quantitative lightness predictions for consistent achromatic patterns and segmentable, inconsistent patterns. We proposed to develop and evaluate algorithms for quantitative lightness predictions from nonsegmentable, inconsistent patterns.

II. STATUS OF RESEARCH EFFORT

A. Lightness and Color Constancy

We made major progress, both theoretical and experimental, on both lightness and color constancy during the past three years. On the experimental side, we developed a method for quantitative measurement of both apparent surface color and the apparent color of the light coming from the surface. Our experiments showed that the two tasks generate dramatically different data from identical stimulus scenes viewed by the same subjects. In the achromatic case, our subjects' surface color matches were invariant under illuminance changes, i.e., the subjects showed nearly perfect lightness constancy. At the same time, the subjects were aware of the illuminance changes: The brightness of the test patch varied monotonically with illuminance. In the analogous chromatic

experiments the data were not so simple, but the apparent surface color matches varied less over illumination variation than the sensory color matches. These were the first published attempts to quantitatively measure multiple intrinsic images in human surface color perception. They have opened up an entire new line of quantitative experimentation on surface color appearance.

1. Experiments. In the first year we completed publication of papers on our initial chromatic constancy measurements (J. Opt. Soc. Amer. A, 1986) and the thresholded-gradient-integration model (Perception and Psychophysics, 1987). We also completed our initial achromatic constancy experiment by expanding the test patch reflectance set from one to four, spanning the gamut from black to white. We ran the three additional test-patch reflectances on the first subject and all four on a second subject. The results, were very clearcut and consistent and reported at the Spring, 1986, meeting of ARVO. A paper was prepared and published in J. Opt. Soc. Amer. A., 1987.

We also significantly extended our chromatic constancy experiments. It was possible that our failure to confirm Land's observations on Mondrians was attributable, in part, to our equal-value constraint. We replaced the equal-Munsell-value papers of the original patterns with colored papers spanning the entire Munsell value scale, from black to white. The data were very similar to those of the equal-value experiment. We also showed that our data were not dependent upon continuous presentation and eye-movements by presenting flashed stimuli. The results of these and other control experiments were presented at the 1987 and 1988 ARVO meetings and in a paper submitted to J. Opt. Soc. Amer. A. (manuscript appended).

The results were once again in apparent conflict with Land's demonstrations and are not consistent with the simplest form of extension of achromatic edge-ratio models to color, e.g., Land's retinex model. It is now clear that the chromatic version of our model cannot be a mere replication of the achromatic model within three cone systems or three opponent systems formed by simple linear combination of the cone systems. It's now clear that a successful model will have to allow separation of illumination and reflectance edges if it is to apply to more than the simplest laboratory stimuli.

We also began collecting data on adaptive hue shifts, for comparison with our simultaneous data. A common problem in evaluation of color percepts under different chromatic adaptations is provision of a stable yardstick, i.e., a standard stimulus with constant

appearance. This has most commonly been done by placing a standard patch of constant chromaticity in one eye, adapted to the standard illuminant, and a test patch in the other eye, adapted to the experimental illuminant. This method suffers from the possibility of contamination due to interaction between the adaptive states of the two eyes (there is recent experimental evidence to justify this concern). We have chosen to avoid this problem by presenting only the test stimulus, with the subject adapted to the experimental illuminant. The constant yardstick is achieved by asking the subject to always adjust the red test patch to a unique red of half-maximum saturation, i.e., to provide an internal standard stimulus. Corresponding adjustments were made for unique green, yellow, and blue, and a neutral gray adjustment. Three adapting illuminants were used, 4000 K, 6500 K, and 10000 K. Three minute adaptation to the test illuminant resulted in much larger shifts of hue than we observed in the simultaneous constancy experiments, comparable to the shifts in our apparent surface color ('paper') matches.

The data, in conjunction with our simultaneous constancy data, show that the visual system has two quite different color constancy strategies. In slightly overly simple terms, slow shifts of illumination over the entire visual field result in normalization of hues, i.e., there is a tendency for a surface to produce approximately the same hue at complete adaptation to the current illuminant. Within scenes the hues of surfaces are primarily determined by the adaptation illuminant. If there are regions in the scene with a different illuminant, the same reflectance will have a different hue, but the observer will nevertheless perceive it to be the same surface color under a different illuminant.

We are currently working on an elaboration of this experiment which will allow us to examine the influence of spatial complexity on adaptive hue shifts.

We also extended our achromatic constancy experiments (J. Opt. Soc. Amer. A., 1987) to simple and complex reflectance arrays illuminated by several different light distributions. In each session one of three illuminance distributions spanned the reflectance array. In one there were two adjacent homogeneous illuminances, separated by an abrupt step. There were nine different illuminance steps matching the illuminance differences from our prior experiments. The other distributions were a linear illuminance gradient and a distribution simulating that produced by a fluorescent tube above and to the side of the reflectance array (similar to that studied by Land and McCann, J. Opt. Soc. Amer., 1971). There were nine steepnesses of each. The lightness results confirmed our first

experiments; the subjects had essentially perfect lightness constancy. The illumination gradients were not, however, invisible, as Land and McCann's analysis would require. All of our illumination gradients were detected as brightness gradients. The brightness results were very systematic, but more complicated, with shallow illumination gradients producing less brightness difference than illuminance steps of the same size. The results of all of the achromatic experiments were summarized in two talks and a paper (Proc. of 6th Scand. Conf. on Image Analysis, 1989), and a detailed data paper on the new experiments has been submitted to J. Opt. Soc. Amer. A.

2. Theory. While our experimental data have answered a number of questions, they have raised even more new ones. Our theoretical progress of the past three years has involved a major increase in the sophistication of our characterization of surface color perception. At the beginning our view was little different from the unsystematic, trivial conceptualizations then (and in some quarters, still) popular. Over the three years we have developed an organized framework that explicitly represents the complexity of surface color perception and the limited role of sensory mechanisms in the perceptual image-analysis task. My human intrinsic-images model (described in detail in my grant renewal proposal) was presented in several professional talks (listed in Section V). A book chapter (see Section IV) and paper on the subject are in preparation. The model's main message is that the human constancy process is more sophisticated than human perception researchers have typically supposed. This complexity makes empirical test of candidate color-constancy algorithms very difficult. Traditional sensory mechanisms can accomplish only part of the processing. The model is being received with interest and a fair amount of resistance. However, related ideas have been presented in less quantitative form in the past, and another laboratory presented interesting work based on very similar concepts at a major national meeting this spring, increasing my (already high) confidence that the model is on the right track [citation?].

One product of the new model is even clearer separation of work on the Arend/Blake thresholded-gradient-integration model from work on surface color perception. The Arend/Blake model is central to understanding brightness and color sensations from complex stimulus arrays, but it is inherently sensory--it makes no direct contribution to the inverse optics problem of deriving properties of surfaces and lights from signals based on cone quantum

catches. At this point the Arend/Blake model can be thought of as providing the input information for the perceptual inferences.

In the case of lightness constancy the improved theoretical understanding was greatly stimulated by participation in an international symposium at an August,1987 meeting in Trieste, Italy. The five symposium participants met again in Wales in 1988 and have corresponded extensively. A book summarizing the participants' work is in preparation for publication by Lawrence Erlbaum Associates.

B. Arend/Blake Model Development

Our early reports of color and lightness constancy experiments were received with great interest by the vision research community, with the result that much of our time and energy was consumed in extension of the constancy work and presentation of those results. As a consequence there was disappointingly little time for further development of the spatial integration model. Nevertheless, we did make some progress toward implementing a version of Blake's integration algorithm for patterns which are neither consistent nor segmentable. Blake's model is analytically identical to ours in many respects, the most important difference being that Blake's model inflexibly applies the "gradient manipulation" type of integration algorithm to all patterns, making poor predictions of the appearance of segmentable, inconsistent patterns, e.g., a shallow linear sawtooth with a dark surround (fig. 1). Blake supplied us with his code, and we have completed the process of converting it to run in our software environment (conversion from UNIX and C to VMS and FORTRAN). The effort was much greater than anticipated and a number of modifications are still required, but we did succeed in getting the model to generate illusory gradient patterns similar to those reported by our human observers, using the circumferential sawtooth and induced sawtooth patterns we have used in our human experimentation. The main remaining barriers to rapid advances in this part of the model work are, on the theoretical side, the slow convergence of the algorithm and, on the experimental side, the absence of good methods of psychophysically measuring gradual spatial changes of brightness. We plan to attack both these problems in the next project period.

We also interacted extensively with the Grossberg group at Boston University concerning their attempts to account for essentially the same family of shallow-gradient illusions that our model was designed to explain. Unlike Blake's model theirs is

structurally very different from ours, using a complex form of local filling-in rather than global integration. It is now clear that their model is unable to account for our observation that our radial sawtooth illusions (modifications of the Craik-OBrien-Cornsweet illusion).are essentially unaffected by reversal of the contrast of the surround luminance. Their model's success in predicting the illusory appearance applies only to one or the other surround luminance, depending on the direction of the sawtooth. Our observations are only qualitative so far, but the phenomena are so robust that there is little doubt that our previously successful brightness matching technique will produce the necessary quantitative evidence. We hope to find time to run this experiment in the coming year.

C. Filling-In Experiments

In the fall of 1986 and briefly in 1988 I worked at SRI in Menlo Park, CA, in collaboration with Drs. Piantanida of SRI and Larimer of NASA Ames Research Center, on experiments investigating the influence of illusory "filled-in" colors on sensitivity to superimposed real light. The experiments were successful, and we have submitted a manuscript for publication. The results of the experiments are very clear. The influence of background light on chromatic flicker sensitivity is not directly attributable to changes in excitation of the surrounding cones, but depends instead on the surround color following the filling-in process. These results have profound implications for further psychophysical study of the organization of opponent color mechanisms.

III. PAPERS

Significant time was devoted during this grant period to reporting results of the research project. In addition to appearance of several articles, I gave a number of invited papers.

Arend, L.E. and Goldstein, R. Lightness and brightness in complex achromatic arrays. Invest. Ophthal. & Vis. Sci., April Supple., 292, 1986.

Arend, L. And Reeves, A. Simultaneous color constancy. J. Opt. Soc. Amer. A, **3**, 1743-1751, 1986.

Arend, L. and Timberlake, G. Reply to Prof. Ditchburn's "Comment on 'What is psychophysically perfect image stabilization? Do perfectly stabilized images always disappear? J. Opt. Soc. Amer. A, **4**, 407-408, 1987.

Arend, L. and Goldstein, R. Lightness models, gradient illusions, and curl. Perception and Psychophysics, **42**, 65-80. 1987.

Arend, L.E. and Goldstein, R. Simultaneous constancy, lightness and brightness. J. Opt. Soc. Amer. A., **4**, 2281-2285, 1987.

Larimer, J., Piantanida, T., Arend, L., and Varner, D. Separation of chrominance and wavelength in color perception. Invest. Ophthal. & Vis. Sci., **28**, March Supple., 93, 1987.

Arend, L.E., Reeves, A., Schirillo,J. and Goldstein, G. Simultaneous color constancy for papers with varying Munsell values. Invest. Ophthal. & Vis. Sci., **28**, March Supple., 213, 1987.

Reeves, A., Arend, L.E., and Schirillo. Simultaneous and successive color constancy. Invest. Ophthal. Vis. Sci., **29**, 162, 1988.

Arend, L. and Goldstein, R. Lightness and brightness in unevenly illuminated scenes. Proceedings of the 6th Scandinavian Conference on Image Analysis. Vol. 1, pp. 499-506.

In Press and Submitted:

Larimer, J., Piantanida, T., Arend, L. and Varner, D. Separation of chrominance and wavelength in color perception. Submitted for publication.

Schirillo, J., Reeves, A. and Arend, L. Perceived depth influences lightness, not brightness of achromatic surfaces. Submitted for publication.

Arend, L., Reeves, A., Schirillo, J, and Goldstein, R. Simultaneous color constancy: Patterns with diverse Munsell values. Submitted for publication.

Arend, L. and Goldstein, R. Lightness and brightness perception in obliquely-illuminated scenes. Submitted for publication.

Arend, L. Multidimensional models of surface color perception. To appear in Gilchrist, A. (Ed.) Lightness, Brightness, and Transparency. Lawrence Erlbaum Assoc., Hillsdale, NJ.

IV. PROFESSIONAL PERSONNEL

Arend, Lawrence E., Principal Investigator

Goldstein, Robert, Research Assistant

Reeves, Adam, nonsalaried part-time collaborator

Schirillo, James, nonsalaried part-time collaborator

V. PROFESSIONAL INTERACTIONS

Papers presented:

Arend, L., and Goldstein, R. "Lightness and brightness in complex achromatic arrays," ARVO Annual Meeting, Sarasota, FL, May, 1986.

Larimer, J., Piantanida, T., Arend, L. and Varner, D. "Separation of chrominance and wavelength in color perception," ARVO Annual Meeting, Sarasota, FL, May, 1987.

Arend, L., Reeves, A., Schirillo, J., and Goldstein, R. "Simultaneous color constancy for papers with varying Munsell values," ARVO Annual Meeting, Sarasota, FL, May, 1987.

Arend, L. "Simultaneous color contrast and constancy," Invited Paper, OSA Topical Meeting on Color Appearance, Annapolis, MD, June, 1987.

Arend, L. "Complexities of lightness perception," Invited Paper, Fourth International Conference on Event Perception and Action, Trieste, Italy, August, 1987.

Larimer, J., Piantanida, T., Arend, L. and Varner, D. "Separation of chrominance and wavelength in color perception," OSA Annual Meeting, Rochester,NY, October, 1987.

Arend,L. "Human color constancy," Colloquium, Center for Biological Information Processing, MIT, October, 1987.

Arend,L.."Contrast and constancy," Invited talk, NASA Ames Research Center, CA, November, 1987.

Arend,L. "Edge ratios and constancy," Invited talk, "Form and Motion" International Conference, Boston University, February, 1988.

Arend,L. "Integration of edge ratio information," Colloquium, Rutgers University, April, 1988.

Arend,L. "Color constancy data and models," European Conference on Visual Perception, Bristol, England, September, 1988.

Arend,L. "Surface color constancy: Data and models," Invited symposium paper, OSA Annual Meeting, Santa Clara, CA, October, 1988.

Other interactions:

Visited laboratories at SRI International and Stanford University for eight weeks, August, September, 1986.

Principal contacts:

SRI

- C. Burbeck
- D. Kelly
- T. Piantanida

Stanford University

- B. Wandell
- D. Brainard

NASA Ames

- J. Larimer

Attended annual meeting of Optical Society of America, Seattle, WA, October, 1986.

Visited vision researchers at Human Resources Laboratory, Williams AFB, AZ., February, 1987. Gave informal lecture on color and lightness constancy experiments.

VI. INVENTIONS

There were no patentable inventions under this project.